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PII: S0927-5398(16)30030-5
DOI: doi: 10.1016/j.jempfin.2016.03.003
Reference: EMPFIN 891
To appear in: Journal of Empirical Finance

Received date: 31 March 2015
Revised date: 22 February 2016
Accepted date: 6 March 2016

Please cite this article as: Levant, Jared, Ma, Jun, Investigating United Kingdom’s Monetary Policy with Macro Factor-Augmented Dynamic Nelson-Siegel Models, Journal of Empirical Finance (2016), doi: 10.1016/j.jempfin.2016.03.003

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Jared Levant†

Jun Ma‡

This Version: February 20, 2016

Abstract

We employ the Dynamic Nelson-Siegel (DNS) model augmented with macroeconomic factors to investigate interactions of yields, real economic activity, and monetary policy in the United Kingdom. By explicitly accounting for the structural break during the early 90s at the time the UK exited the Exchange Rate Mechanism of the European Monetary System, we document a number of interesting findings. Specifically, there is evidence of a great moderation in the volatility of the term structure post-1992. At the same time, there is a significant reduction of the loading parameter in the DNS model, which suggests a greater influence of the monetary policy and economic activity on the bond market. We find with others that the level and slope yield curve factors are related to inflation expectations and monetary policy, respectively. Interestingly, the curvature factor which has been elusive in its relationship to macroeconomic fundamentals is found to be more strongly related to economic activity post-1992.

JEL: C51, E43

Keywords: Monetary policy, Term Structure, Macroeconomic Fundamentals, Dynamic Nelson-Siegel model, Factor-augmented VAR, Structural Break

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Abstract

We employ the Dynamic Nelson-Siegel (DNS) model augmented with macroeconomic factors to investigate interactions of yields, real economic activity, and monetary policy in the United Kingdom. By explicitly accounting for the structural break during the early 90s at the time the UK exited the Exchange Rate Mechanism of the European Monetary System, we document a number of interesting findings. Specifically, there is evidence of a great moderation in the volatility of the term structure post-1992. At the same time, there is a significant reduction of the loading parameter in the DNS model, which suggests a greater influence of the monetary policy and economic activity on the bond market. We find with others that the level and slope yield curve factors are related to inflation expectations and monetary policy, respectively. Interestingly, the curvature factor which has been elusive in its relationship to macroeconomic fundamentals is found to be more strongly related to economic activity post-1992.

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1. INTRODUCTION

This paper employs the Macro-Factor Augmented Dynamic Nelson-Siegel model to study the interactions of yields factors and the macroeconomic factors in the United Kingdom from Jan. 1985 to Dec. 2006. A growing empirical literature investigates the interaction of the macro-economy and term structure. Utilizing the Nelson-Siegel yield curve model, Chen and Tsang (2013) find that yield curve factors can explain exchange rate movements and excess currency returns. Wu (2002), Ang and Piazzesi (2003), and Joslin et al. (2014), utilize principal components analysis to decompose the term structure into three orthogonal latent yield curve factors within a no-arbitrage affine term structure model (ATSM) framework to investigate macroeconomic phenomena through the term structure. Diebold et al. (2006, henceforth DRA) and Bianchi et al. (2009, henceforth BMS) employ the Dynamic Nelson-Siegel (DNS) factor model framework of Diebold and Li (2006) to obtain yield curve factors. It is this latter strand of literature that this paper is most closely related.

Many of the papers mentioned above incorporate macroeconomic fundamentals such as inflation, monetary policy rate, and a proxy for economic activity into their model framework. Although integrating macroeconomic fundamentals into term structure estimation does alleviate the issue of unspanned macro risk factors, it does not address the noted parameter instability associated with the term structure. For the US, this issue has been investigated in the works of Cogley (2004), Rudebusch and Wu (2008), Startz and Tsang (2010) and Levant and Ma (2014), and for the UK, Benati (2004) and BMS. Wong et al. (2011) find that the strong correlations between the yields dynamics in US and Canada dissipate after Canadian monetary policy reforms in the early 1990s.

Utilizing a state-space framework, this paper seeks to establish a clear relationship between latent Nelson-Siegel yield curve factors and observable macroeconomic fundamental variables, by explicitly accounting for the structural instability of the UK term structure. We present strong evidence that the interactions between the UK term structure and macro-economy changed significantly with the inception of inflation-targeting post-October 1992. Specifically, we document a substantial decrease in term structure volatility post-1992, which coincides with the regime in which the monetary policy and economic activity tend to have a greater influence.

Coroneo, Nyholm, and Vidov-Koleva (2011) find the NS model is close to being arbitrage-free when applied to the US market, although it does not explicitly impose these restrictions.
on the bonds market. We also document a bi-directional interaction between the slope factor and the macro-economy for the pre-1992 era and a bi-directional interaction between the curvature factor and the macro-economy post-1992.

The paper is organized as follows. Section 2 presents the Macro-Factor Augmented Dynamic Nelson-Siegel model. Section 3 describes the yields and macroeconomic data. Section 4 presents and discusses the estimation results. Section 5 concludes.

2. MODELS

2.1 Dynamic Nelson-Siegel Model

DRA estimates the Diebold and Li (2006) factorization of the NS yield curve model according to a state-space framework. The advantage of this approach as compared to the two-step approach used in the DL paper is that estimation of the latent NS yield curve factors and all model parameters including the loading parameter \( \lambda \) are done in one step. Factor estimation uncertainty is ignored in the two-step approach. The measurement equation for the DRA state-space framework for the DL factorization is

\[
\begin{bmatrix}
y(t(m_1)) \\
y(t(m_2)) \\
\vdots \\
y(t(m_N)) \\
\end{bmatrix} =
\begin{bmatrix}
1 & \frac{1-e^{-\lambda m_1}}{\lambda m_1} & \frac{1-e^{-\lambda m_1}}{-e^{-\lambda m_1}} \\
1 & \frac{1-e^{-\lambda m_2}}{\lambda m_2} & \frac{1-e^{-\lambda m_2}}{-e^{-\lambda m_2}} \\
\vdots & \vdots & \vdots \\
1 & \frac{1-e^{-\lambda m_N}}{\lambda m_N} & \frac{1-e^{-\lambda m_N}}{-e^{-\lambda m_N}} \\
\end{bmatrix}
\begin{bmatrix}
\beta_{1t} \\
\beta_{2t} \\
\beta_{3t} \\
\end{bmatrix} +
\begin{bmatrix}
\varepsilon_t(m_1) \\
\varepsilon_t(m_2) \\
\vdots \\
\varepsilon_t(m_N) \\
\end{bmatrix}
\]  

or written in matrix notation as

\[
y_t(m) = \Lambda(\lambda)F_t + \varepsilon_t, \quad \varepsilon_t \sim N(0, G), \quad t = 1, \ldots, T. \tag{2}
\]

where \( y_t(m) \) is the vector of yields as functions of maturity, \( F_t = [\beta_{1t}, \beta_{2t}, \beta_{3t}]' \) where \( \beta_{1t}, \beta_{2t}, \) and \( \beta_{3t} \) represent the time-series of the level, slope, and curvature yield curve factors, respectively.\(^2\) The measurement error variance-covariance, \( G \), is restricted to be diagonal which is a standard assumption for yield models. The transition equation is represented by

\[
\begin{bmatrix}
\beta_{1t} \\
\beta_{2t} \\
\beta_{3t} \\
\end{bmatrix} =
\begin{bmatrix}
\mu_{L_t} \\
\mu_{S_t} \\
\mu_{C_t} \\
\end{bmatrix} +
\begin{bmatrix}
a_{11} & a_{12} & a_{13} \\
a_{21} & a_{22} & a_{23} \\
a_{31} & a_{32} & a_{33} \\
\end{bmatrix}
\begin{bmatrix}
\beta_{1t-1} \\
\beta_{2t-1} \\
\beta_{3t-1} \\
\end{bmatrix} +
\begin{bmatrix}
\eta_{L_t} \\
\eta_{S_t} \\
\eta_{C_t} \\
\end{bmatrix} \tag{3}
\]

\(^2\) Bold-faced script indicates a vector or matrix.
or written in matrix notation as

\[ F_t = \mu + AF_{t-1} + \eta_t, \quad \eta_t \sim N(0, Q), t = 1, \ldots, T \]  

which can be equivalently written as

\[ (F_t - (I - A)^{-1}\mu) = A(F_{t-1} - (I - A)^{-1}\mu) + \eta_t. \]  

DRA try two identification schemes of the state-space framework where the variance-covariance matrix, \( Q \), is allowed to be non-diagonal, thus, permitting shocks between factors and restricted to be diagonal, imposing no contemporaneous correlations between factors. They find the difference in the parameter estimates between these identification schemes is negligible with and without macro-factors added to the model.

### 2.2 Macro-Factor Augmented Dynamic Nelson-Siegel Model

Similarly to DRA, we add macro-factors to the DNS state-space framework in order to investigate the relationship between the NS factors and macroeconomic fundamentals. The United Kingdom data included are monetary-policy interest rate \((R_t)\), total industrial production \((IP_t)\), and inflation expectations \((IE_t)\). The choice for these particular macro-factors comes from what is widely considered to be the minimum set of macroeconomic variables required to model fundamental macroeconomic dynamics as argued by Rudebusch and Svensson (1999) and Kozicki and Tinsley (2001). Following the DRA set up, the measurement equation for this investigation is formulated as

\[
\begin{bmatrix}
y^1_t \\
y^2_t \\
\vdots \\
y^N_t \\
R_t \\
IP_t \\
IE_t \\
\end{bmatrix} = \begin{bmatrix}
1 & \frac{1-e^{-\lambda m_1}}{\lambda m_1} & \frac{1-e^{-\lambda m_2}}{\lambda m_2} & \ldots & \frac{1-e^{-\lambda m_N}}{\lambda m_N} & 0 & 0 & 0 \\
1 & \frac{1-e^{-\lambda m_1}}{\lambda m_1} & \frac{1-e^{-\lambda m_2}}{\lambda m_2} & \ldots & \frac{1-e^{-\lambda m_N}}{\lambda m_N} & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\
1 & \frac{1-e^{-\lambda m_1}}{\lambda m_1} & \frac{1-e^{-\lambda m_2}}{\lambda m_2} & \ldots & \frac{1-e^{-\lambda m_N}}{\lambda m_N} & 0 & 0 & 0 \\
0 & 0 & 0 & \ldots & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & \ldots & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & \ldots & 0 & 0 & 0 & 1 \\
\end{bmatrix} \begin{bmatrix}
L_t \\
S_t \\
C_t \\
R_t \\
IP_t \\
IE_t \\
\end{bmatrix} + \begin{bmatrix}
\varepsilon^1_t \\
\varepsilon^2_t \\
\vdots \\
\varepsilon^N_t \\
0 \\
0 \\
0 \\
\end{bmatrix}
\]  

or written in matrix notation as

\[ y^m_t = \Lambda(\lambda)F^A_t + \varepsilon_t, \quad \varepsilon_t \sim iid N(0, G), t = 1, \ldots, T, \]  

where \( F^A_t = [L_t, S_t, C_t, R_t, IP_t, IE_t]' \). The measurement errors are assumed to be uncorrelated again and therefore \( G \) is diagonal as is standard in the literature. To ensure the macro-factors do
not affect the yields curve as is typical in the yields model with unspanned macro risks, the loading factors contribution of the macro-factors are restricted to zero. Also, because the macro-factors are typically assumed to be directly observable without measurement errors the loading factors are set at one and the errors associated with each macro-factor are set to zero. The transition equation is as follows

\[
\begin{bmatrix}
L_t \\
S_t \\
C_t \\
R_t \\
IP_t \\
IE_t
\end{bmatrix}
= \begin{bmatrix}
\mu_t \\
\mu_t \\
\mu_t \\
\mu_t \\
\mu_t \\
\mu_t
\end{bmatrix}
+ \begin{bmatrix}
a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\
a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\
a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\
a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\
a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\
a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66}
\end{bmatrix}
\begin{bmatrix}
L_{t-1} \\
S_{t-1} \\
C_{t-1} \\
R_{t-1} \\
IP_{t-1} \\
IE_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
\eta_{L_t} \\
\eta_{S_t} \\
\eta_{C_t} \\
\eta_{R_t} \\
\eta_{IP_t} \\
\eta_{IE_t}
\end{bmatrix}
\tag{8}
\]

or written in matrix notation as

\[
F^A_t = \mu + AF^A_{t-1} + \eta_t, \quad \eta_t \sim iid \, N(0, Q), t = 1, \ldots, T
\tag{9}
\]

where \(F^A_t\) is the vector of state variables that include both the latent yields factors and the observed macro factors. Equations (7) and (9) constitute what we will refer to as the macro-factor augmented Dynamic Nelson-Siegel (MFA-DNS) model. In this investigation, we assume \(Q\) is diagonal for the sake of parsimony, given the finding in DRA that parameter estimates changed marginally when estimated under a diagonal \(Q\) matrix or non-diagonal \(Q\) matrix. This identification specification restricts interactions of the factors (latent and macro) only through the VAR coefficients in \(A\).

Compared to the yields only DNS model given by equations (2) and (4), in the MFA-DNS model the prediction of the latent factors benefit from the additional information provided by the added macroeconomic variables, which in turn contributes to possibly better term structure estimation. At the same time, having both the NS latent factors and macro-factors in a VAR framework as set up by equation (8) allows for estimations of impulse responses so as to investigate the interactions between the NS factors and the macro-factors.

3. DATA

The end of the month zero-coupon government yields data is constructed using piecewise cubic polynomials to model forward rates. The yields were constructed by Anderson and Sleath (1999) and supplied by Wright (2011). The maturities under investigation are the 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 48, 60, 72, 84, 96, 108 and 120-month over the period Jan. 1985 through Dec.
2006 when analyzing the link between NS factors and macro-factors with the MFA-DNS model.\(^3\) In Table 1, we present descriptive statistics for various maturity yields. The increasing pattern of the yield means as we go to longer maturities indicates an upward sloping yield curve generally for the UK term structure.

![Insert Table 1 here](image)

We utilize the monetary policy-related interest rate variable, industrial production, and inflation expectations as the unspanned macro risk factors to create a macro-factor augmented DNS model. The policy interest rate is introduced into the framework as the annual percent change in the less than 24 hour interbank rate for the United Kingdom. Industrial production data is also transformed into annual growth rates for the purposes of this analysis. Inflation expectations come from the Consumer Opinion Surveys of the future tendency of inflation compiled by the European Commission and National Indicators for the United Kingdom. This data enters into the state-space framework as net percent. Data on the three macro-factors come from the FRED database. We present the descriptive statistics for these macro-factors at the bottom of Table 1. Figure 1 gives a visual for the time-series dynamics of the 3-month, 24-month, and 120-month maturities along with the macroeconomic variables. Notably, there is generally a downward trend in all yields data as well as the inflation expectation.

![Insert Figure 1 here](image)

4. EMPIRICAL RESULTS

In this section, we present the estimation results of the MFA-DNS model to shed light on the interactions of the UK yields factors, economic activity, and monetary policies. We utilize maximum likelihood estimation via the Kalman filter to obtain parameter estimates and smoothed estimates of the latent factors in the model as set up by equations (7) and (9). Estimation procedure and the smoothing algorithm are standard and details can be found in Kim and Nelson (1999). To avoid being stuck at the local maxima of the log likelihood function we estimate all models below using a large set of random initial values to ensure we find the global maximum.

---

\(^3\) We use the Jan. 1985 start date because UK inflation expectations data is not available prior to this date. We end our sample period in Dec. 2006 to avoid the financial crisis and the resulting near zero interest rate era for which a Gaussian type of term structure model such as the DNS model would be a poor approximation.


4.1 Estimation Results of the Restricted Model

The estimation results of the whole sample period are given in Table 2. Many of the off-diagonal elements are insignificant for the coefficient matrix $A$, but the significant coefficients give insight into the interaction of the yield curve and macroeconomic fundamentals. The growth rate of the monetary policy-rate has significant dependence on the curvature factor while the growth rate of industrial production has significant dependence on the slope factor. The negative sign of the growth rate of industrial production associated with the lagged slope factors (-0.10) points to the predictability of the real economic activity based on the yield curve slope, as have been documented by Estrella et al. (2003) among many others. It is straightforward to show that the slope factor is $S_t = \lim_{m \to 0} y(m) - \lim_{m \to \infty} y(m)$ (see Levant and Ma (2014) for detailed discussions). Therefore an increase of the slope factor implies a flatter yield curve, which increases the likelihood of a recession. The relatively large coefficient (0.67) of the level factor for inflation expectations gives support to the connection inflation expectations has with the level factor. Finally the loading parameter $\lambda$ is estimated to be 0.056 with a standard error of 0.001.

[Insert Table 2 here]

4.2 Structural Break in Oct. 1992 and Estimation Results of the Unrestricted Model

As pointed out by Levant and Ma (2014) among many others, the yields curve dynamics are often subject to regime shifts due to monetary policy changes. As such it is important to account for these structural breaks in order to more accurately extract the latent yields factors and study their interactions with economic activity and monetary policy. In September 1992, the UK exited the Exchange Rate Mechanism of the European Monetary System. Three weeks later on October 8, 1992 the Chancellor of the Exchequer, Norman Lamont, established an inflation target of 1%-4% for the annual retail price index (RPI). During the period before this policy change UK monetary policy targeted monetary aggregates such M0 (narrow money) as a way of corraling inflation but found monetary aggregates to be poor nominal anchors for inflation. Exchange-rate-based nominal anchors were then utilized from 1987 until those proved poor anchors as well causing the UK to leave the ERM in 1992. Because this policy regime change is known a priori we choose to impose the exogenous structural break in October 1992 and allow all model parameters to change after this break date. Our goal is to first test the statistical
significance of this monetary policy change on the UK term structure, and then re-estimate the model by imposing this break if this break turns out to be statistically significant. To this end we break the whole sample period into two: the period of Jan. 1985 – Sep. 1992 and the period of Oct. 1992 – Dec. 2006. We estimate the MFA-DNS model separately for each of these two sub-sample periods and report the estimation results in Tables 3 and 4.

\[\text{Insert Table 3 here}\]

\[\text{Insert Table 4 here}\]

In order to test the statistical significance of this break, we construct a simple Likelihood Ratio (LR) test as below:

\[LR = 2 \times (LR_{u1} + LR_{u2} - LR_r)\]

Where, \(LR_{u1} = 1329.3\) and \(LR_{u2} = 4787.1\) are the log likelihood values for the two sub-sample periods respectively, and \(LR_r = 5258.4\) is the one for the restricted model without the break. The resulting value of the LR test statistic is 1716 with a \(p\)-value being essentially zero given that the test statistic follows a \(\chi^2(66)\) distribution. Therefore it indicates a firm rejection of the null hypothesis of no break at any statistical significance level.

There are a number of differences of the parameters estimates across the two periods of pre- and post-1992. First of all, there are significant reductions in the volatility of the yields factor shocks as reported in the estimated \(Q\) matrices. All three yields latent factors shocks experience about one-third of a reduction in their volatility, and judged based on their standard errors these reductions are statistically significant. The two macroeconomic variables shocks, namely the monetary policy rate and the industrial production, also experience a similar volatility reduction, although the inflation expectation appears to be the only exception. Secondly, yields dynamics also appear to have experienced a regime shift. For example, while the industrial production depends negatively upon the lagged slope factor pre-1992 this relationship seems to have disappeared post-1992. At the same time, the industrial production becomes significantly dependent upon the curvature factor post-1992 although there does not appear to exist any direct interdependence between these two pre-1992.

Finally, our estimation results reveal that the loading parameter \(\lambda\) takes two distinct values in the two sub-sample periods. Specifically, the parameter estimate of \(\lambda\) is 0.065 with a standard error of 0.002 for the period of pre-1992 but it decreases to 0.042 with a standard error
of 0.001 post-1992, and based on their small standard errors these changes are highly significant. The variation of this parameter permits yields latent factors to change in terms of how they are weighted on yields across different regimes. In order to better visualize this we plot the loadings of slope and curvature factors for these two regimes in Figure 2.

Notably, the low-\(\lambda\) regime implies a greater influence of the slope factor relative to the level factor across all maturities while the high-\(\lambda\) regime implies that the level factor has a relatively greater influence on yields determination. As a result, the same slope factor shock tends to generate a larger impact on the yield curve in the low-\(\lambda\) regime (post-1992) relative to the high-\(\lambda\) regime (pre-1992). For the curvature factor, the low-\(\lambda\) regime implies a slightly smaller influence for short-term maturities but much greater influence for maturities longer than approximately 36 months. Because the slope factor and the curvature factor, as to be argued below, tend to approximate the real economic activity and monetary policy, and the level factor is usually associated with the inflation expectation, this implies a generally greater influence of the real economic activity and monetary policy on the yields determination relative to the inflation expectation in the low-\(\lambda\) regime.

To better visualize the connections between the yields latent factors and the macroeconomic risk factors, in Figure 3 we plot the smoothed estimates of the level, slope, and curvature factors throughout the whole sample period after accounting for the structural break. Each figure also contains plots of corresponding empirical (approximate) factors constructed using observed yields and macro-factors as a means of comparison. To facilitate the comparison, we standardize each series by subtracting its mean and dividing by its standard deviation. The empirical factors are calculated in the following manner:

\[
\begin{align*}
\text{Level} & = \frac{y(3) + y(24) + y(120)}{3} \\
\text{Slope} & = y(3) - y(120) \\
\text{Curvature} & = 2y(24) - (y(120) + y(3))
\end{align*}
\]

The first panel of Figure 3 shows the smoothed level and empirical level match each relatively closely throughout the sample period. The correlation between the Inflation expectations and the smoothed level factor is 0.78. The smoothed slope factor is shown in the
second panel along with its empirical counterpart and the policy interest rate. With how well the plots of the smoothed slope factor and the policy rate resemble one another, it can be concluded that slope and monetary policy are related for the UK. They have a correlation of 0.52 which supports this visual finding. The plots for the curvature factors and industrial production are shown in the last panel. After 1992, the two plots appear to display more similar trajectories. In particular, although the correlation for these two for the whole sample period is 0.15 but is as high as 0.43 for the post-1992 period, which indicates a stronger correlation between the curvature factor and the real economic activity after the monetary policy change in 1992.

4.3 Impulse Response Analysis

In this section we discuss and compare four groups of impulses responses across the two regimes by focusing on the statistically significant responses: macro responses to macro shocks, macro responses to yield shocks, yield curve responses to macro shocks, and yield curve responses to yield shocks. Figure 4 and 5 plot the impulses responses, together with their 95% confidence bands (based on Monte Carlo simulations with 5000 draws), for the periods of pre-1992 and post-1992.

[Insert figure 4 here]

[Insert figure 5 here]

The macro-factor responses to macro shocks in this paper follow suit with the findings of DRA and Rudebusch and Svensson (1999). It is interesting to note that although the response of the policy rate to the industrial production shocks are minimal and insignificant pre-1992, an increase in industrial production shocks gives rise to a persistent and significant increase in the policy rate post-1992, consistent with the Taylor-rule type of monetary policy rule which tends to counter the effects of a possibly overheating economy by raising the cost of capital. On the other hand, the industrial production increasing in response to an increase to the policy rate shock during pre-1992 period is counterintuitive, but this response changes its direction during post-1992 period. The policy rate rises significantly with inflation expectations pre-1992 but such an increase becomes insignificant post-1992. However, note from Figure 1 that the inflation expectation is also much less variable post-1992 which may cause the identification of
policy impact on the inflation expectation to be more challenging. Finally but not least interestingly, the inflation expectation tends to rise in response to an increase in the policy rate pre-1992 which is puzzling but corroborates the findings in the literature that documents the price puzzle (see e.g., Dueker 2006). However, this puzzle disappears during the post-1992 period. During this period the inflation expectation declines following a rise in the policy rate.

The macroeconomic fundamentals response to yield curve shocks offers interesting insights into the interaction of the UK macro-economy with the term structure. An increase in the level factor increases the inflation expectations post-1992 but this effect is insignificant pre-1992. An increase to slope (a flattening yield curve) significantly decreases the industrial production pre-1992 but such an effect is insignificant post-1992. On the other hand, an increase in the curvature factor tends to increase the industrial production for both periods.

Yield curve responses to macro shocks complete the duality of the interaction between the macro-economy and the term structure. Similar to DRA in their impulse response analysis for the US, this paper finds that the curvature factor shows negligible response to the real economic activity during pre-1992 period. However, during post-1992 period, increases in the industrial production lead to highly significant and persistent increases in the curvature factor, and increases in the monetary policy rate lead to persistent and significant declines in the curvature factor. These findings suggest that the curvature factor which has been elusive in its relationship to macroeconomic fundamentals is found to be more strongly and positively related to the economic activity post-1992. During the inflation-targeting era of the UK, the real economic activity seems to be strongly related to the curvature factor. The slope factor experiences persistent and significant increases from positive shocks to the industrial production post-1992 while this response is insignificant pre-1992. The positive responses of the slope factor to the industrial production post-1992 is in accordance with a central bank making the yield curve less positively sloped by raising the short end of the term structure to slow down the overheated economy. Increases in inflation expectations lead to a flattening yield curve pre-1992 while the responses are the opposite direction but barely significant post-1992. The level factor is affected by the inflation expectations in both periods although the effect is larger in the first sub-sample period.

Lastly, an analysis of yield curve responses to yield curve shocks shows a great degree of persistence along the diagonal in both periods. Increases in the level factor decrease both the
slope and curvature factors significantly pre-1992 but only the curvature factor significantly post-1992. Positive shocks to the slope factor decrease the curvature factor in both periods but have opposite effects on the level factor in two periods.

5. CONCLUSION

This paper investigates the UK yields-macro interactions in response to changes in monetary policy. The October 1992 monetary policy change to inflation-targeting from exchange-rate and monetary aggregate anchoring for inflation is employed as a reference to compare the yields-macro interaction across monetary regimes. Using a macro-factor augmented Dynamic Nelson-Siegel (DNS) yield curve model this paper establishes concrete links between each yield curve factor and macroeconomic fundamentals for the UK.

We find the level factor appears to be directly related to inflation expectations across monetary regimes. The slope factor is related to business cycles and monetary policy across regimes. The elusive link between the curvature factor and macroeconomic fundamentals becomes less obfuscate during the inflation-targeting regime where it is related with real economic activity. The correlation between the curvature factor and industrial production achieves its highest value post-1992 and impulse responses point to a highly significant bi-directional interaction between the two during this period.

We find evidence of a great moderation in the term structure volatility after 1992 by explicitly accounting for the structural break. At the same time, we find the value of the loading parameter in the DNS model decreases substantially, which implies a greater influence of the real economic activity and the monetary policy on the yields determinations during this period that features the inflation-targeting.
REFERENCES


Table 1

<table>
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<th>Maturity</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>Minimum</th>
<th>Maximum</th>
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Maximum Log Likelihood Value: 5258.4
Loading Parameter ($\lambda$): 0.056 (0.001)

Note: Numbers in parentheses are standard errors, and parameters estimates that are statistically significant at the 95% level are in bold.
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Maximum Log Likelihood Value: 1329.3
Loading Parameter ($\lambda$): 0.065 (0.002)

Note: Numbers in parentheses are standard errors, and parameters estimates that are statistically significant at the 95% level are in bold.
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<td>$R_t$</td>
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<td>(0.02)</td>
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<td>$IP_t$</td>
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<td>(0.06)</td>
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<td>$IE_t$</td>
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<td>(0.21)</td>
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Maximum Log Likelihood Value: 4787.1
Loading Parameter ($\lambda$): 0.042 (0.001)

Note: Numbers in parentheses are standard errors, and parameters estimates that are statistically significant at 95% level are in bold.
Figure 1. Representative Yields and Macroeconomic Variables
Figure 2. Factors Loadings across Regimes

Note: Regime 1 refers to the pre-1992 period and regime 2 refers to the post-1992 period. The slope factor loadings are computed as $\frac{1-e^{-\lambda m}}{\lambda m}$ using different $\lambda$ values in two regimes for all maturities. The curvature factor loadings are computed as $\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}$ again using different $\lambda$ values in two regimes for all maturities.
Figure 3. Smoothed Factors and Macroeconomic Variables: Unrestricted Model

Note: The empirical level factor is defined as the 120 month yield to maturity. The empirical slope factor is the difference between the 3 and 120 month maturities. The empirical curvature factor is twice the 24 month maturity minus the sum of the 3 and 120 month. The results are based on the unrestricted model in which a structural break in 1992 October is accounted for.
Figure 4. Impulse Responses of Factors: 1985:1-1992:9

Note: Dotted lines are the 95% confidence bands of the impulses responses based on the Monte Carlo simulation using 5000 draws.
Figure 5. Impulse Responses of Factors: 1992:10-2006:12

Note: Dotted lines are the 95% confidence bands of the impulses responses based on the Monte Carlo simulation using 5000 draws.
Highlights

- We fit a macro-factor augmented dynamic Nelson-Siegel model to the UK yields data.
- We impose a structural break in Oct. 1992 when UK exited the Exchange Rate Mechanism of the European Monetary System.
- We find a greater influence of the monetary policy and economic activity on the bond market post-1992.
- The curvature factor is found to be directly related to economic activity post-1992.
- We find evidence of a great moderation in the volatility of the term structure post-1992.